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A Side Impact Sub-System Test Device - Sled to Sled Test Setup

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Paper was presented at the 22nd Annual Workshop on Human Subjects for Biomechanical Research. This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

ABSTRACT

A side impact sub-system test device was designed and fabricated at Wayne State University. This test setup involves a bullet sled, a target sled and a simulated door. The bullet sled has a weight of 3000 lbs and strikes the initially stationary target sled and the simulated door at a velocity of 13 m/s. The door then impacts a test subject placed on a seat attached to the target sled. The velocity pulses of the target sled and simulated door are tuned by means of three interfaces: a large spring between the bullet sled and simulated door, an energy absorbing (EA) pad between the bullet sled and target sled and a second EA pad between the target sled and simulated door. The velocity profile is currently programmed to simulate a mid-size passenger car subjected to a side impact by a moving deformable barrier. The first and second velocity peaks are 10 m/s and 7 m/s, respectively. The simulated door has four contact beams instrumented with load cells to interact with the shoulder, thorax, abdomen and pelvis of the test subject.

Two cadaveric tests were conducted using this device. The cadavers were instrumented with multiple accelerometers and an EPIDM chest band with 40 strain gages. In one cadaver test, there was 102 mm (4 inch) space, but no padding, between the rigid door and the test subject. In the other cadaver test, there was a pad of 102-mm thick (23 psi paper honeycomb for the shoulder and pelvis beams, 15 psi for the thorax and abdomen beams), but there was no space between the simulated door and the test subject. The autopsy data showed that both of the cadavers had an AIS 4 chest injury. The chest band data showed that the impacted side chest deformation is less but the duration is longer in the padded wall impact than in the rigid wall impact.

Seven SID dummy tests were also conducted using this sled-to-sled setup. The interface between the door and test subject were divided into four categories: (1) 4-inch space but no padding; (2) 4-inch 15/23 psi paper honeycomb pad but no space; (3) 4-inch ARCEL pad but no space and (4) 4-inch space, no padding and no shoulder engagement. Experimental results showed that: (1) only ARCEL pads provided a Thoracic Trauma Index (TTI) of 77 g's which was less than the tolerance of 85 g's set by FMVSS 214; (2) For all of the tests, Average Spine Acceleration (ASA) exceeded the human tolerance limit of 30 g's proposed by Cavanaugh et al. (1993a), and paper honeycomb pads bottomed out and provided the lowest ASA (50 g's); (3) TTI and ASA increased dramatically if padding was not used; (4) TTI and ASA were the highest if there were no shoulder engagement and no padding. When compared with 9-m/s Heidelberg type sled test results, the sled-to-sled test data were that (1) for unpadded impacts, TTI and ASA were increased by 18% and 78%, respectively; (2) for padded wall impacts using 15/23 psi paper honeycomb, TTI and ASA were increased by 54%, and 35%, respectively. This implied that a sled-to-sled test, using the current

velocity pulse with a velocity peak of 10 m/s, is more severe than a corresponding 9-m/s Heidelberg type sled test. In order to reduce impact severity, the door-occupant contact velocity should be lowered by either strengthening automotive side structures or delaying door-occupant interaction, and the side door should be adequately padded so that padding does not bottom out.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) requires all passenger cars sold in the U.S. to pass a new side impact dynamic test specified in FMVSS 214, according to a phase-in schedule. In this dynamic test, a 3000-lb moveable deformable barrier is accelerated to 33.5 mph and impacts a test vehicle at a crabbed angle of 27 degrees. Since such a full scale test is very expensive, it is advantageous to develop component test methodologies to determine design parameters of car structures at the early design stage.

The Heidelberg-type sled test method is widely used due to its simplicity. A sled is accelerated to a desired velocity and suddenly decelerated. A test subject, placed on a long bench seat impacts a stationary simulated door during sled deceleration. Since this method was first used in the University of Heidelberg, it is referred to as the Heidelberg-type method in this paper. Variations of this test utilize a HYGE sled. Eppinger et al. (1984) conducted a series of this type of side impact cadaveric tests and concluded that the Thoracic Trauma Index (TTI) was strongly related to cadaver injuries. TTI was later modified for the Side Impact Dummy (Morgan et al, 1986) and incorporated into FMVSS 214. Cavanaugh et al. (1993a) conducted a series of 17 cadaveric tests using a similar test setup at Wayne State University. In their tests, in addition to accelerations of ribs 4 and 8 and of T1 and T12, thoracic compression and contact forces at the level of shoulder, thorax, abdomen and pelvis were also available. It was found that the best chest injury criterion was ASA, followed by VC, in this test series.

However, Deng (1988) argued that the Heidelberg type sled test did not mimic a typical side impact. In side impact, an initially stationary subject is impacted by a moving door. The test subject has a minimal effect on the overall door kinematics. Lau (1991) made a comparison of frontal and side impact using a spring-mass model. He found that Heidelberg type sled tests did not simulate the side impact punch, and may not be valid for judging effects of padding and space.

In order to simulate a typical side impact punch, velocity profiles from a full scale test should be duplicated in sub-system tests. The velocity trace at one location of the door may be different from that at another location. A typical velocity trace should be chosen to represent the impact severity for the region of interest in the test subject.

Some dynamic side impact sub-system test procedures have been reported by Haland and Pipkorn (1991), Lindquist (1991), Fukushima et al. (1991) and Ohlund and Saslecov (1991). These procedures were based on a similar principle: a moving door, which was initially far away from the test subject, was accelerated to a desired velocity and impacted a stationary test subject. the door velocity was constant or decreased during the impact. Therefore, these procedures did not simulate the whole velocity pulse of the door, and cannot be easily used to study some basic side impact issues, such as sitting positions and effects of padding and space.

Under the sponsorship of the Centers for Diseases Control and Prevention, a sled-to-sled sub-system side impact test methodology was conceived in 1992. This paper describes the development of test procedures and preliminary results of the dummy and cadaveric tests.

TEST SETUP

The sled-to-sled test setup is shown in Figure 1. This setup involved two sleds: a bullet sled and a target sled. A simplified drawing of the setup is presented in Figure 2. The items numbered below are illustrated in Figure 2. The bullet sled (6) had a weight of 3000 lbs and simulated a striking car. It was accelerated by an accelerator to a velocity of Vs, and impacted the target sled (1) which was cushioned by an energy absorber EA2 (5). The target sled (1) simulated a struck car which was at an impact angle of 90 degrees to the striking car. The target sled was initially stationary, and was stopped by a snubber after the impact was over. The deceleration distance of the snubber was set to a very high value (48 inch) and the target sled was decelerated slowly to minimize the impact severity of the second impact of the test subject to the far side of the seat. The impactor (7) was mounted on the striking sled (6), and also had a velocity of Vs. The front face of the impactor (7) compressed a large spring (8). The other end of the spring was attached to a piston (10). Since the door (11) was fixed to the piston (10), the door and piston would have the same velocity of Vd. The door impacted the left side of a test subject (2) located on a seat (3). After impact, the test subject was stopped by thick soft energy absorbing material EA3 (12). The door intrusion was 150 mm (can be up to 250 mm), and was limited by the energy absorber EA1 (4). The piston was supported by the main support (9) which was mounted on the target sled (1). A one-way mechanism using a wedge and pulley was inserted between the main support (9) and the front plate of the piston (10), so that the simulated door did not rebound after the impact.

The door (11) can be a real or simulated one. One example is a deformed door which was crushed in an actual side impact or by a moving barrier. However, a simulated door with four contact beams was used in the current setup. In order to make a direct comparison of the sled-to-sled test results to the existing Heidelberg type sled test data at Wayne State University, this simulated door was made per descriptions by Cavanaugh et al. (1990). It had four contact beams interacted with the shoulder, thorax, abdomen and pelvis. Instrumentation including load cells and accelerometers were attached to the simulated door at four levels to measure the forces of contact. The inertial effect of the mass in front of a load cell sensor was eliminated by a mass-corrected method. The mass-corrected method was tested by several runs at different speeds, without a test subject interacting with the simulated door. It was found that the mass-corrected load cell outputs were close to zero. A knee load cell was also attached to the door to measure the knee contact force. A half-inch pad covered by a piece of vinyl was taped to the seat to generate friction between the seat and test subject.

A car-to-car side impact can be characterized by velocity traces of the striking car, target car and door, which can be represented by Vs, Vt and Vd in the sled-to-sled test. In this sled-to-sled setup, the velocity profiles can be programmed to represent different doors, different cars or different impact conditions, by an appropriate design of energy absorbers EA1 (4) and EA2 (5). The velocity pulses were currently configured to simulate a mid-size car subjected to a 33-mph barrier impact, as shown in Figure 3. These velocity profiles were used for all of the dummy and cadaveric tests presented in this paper. As can be seen in the figure, the door was accelerated to 10 m/s within 20 ms, and started to contact the test subject at 23 ms after impact if a four-inch space was available between the door and test subject. After 50 ms, the door and target sled reached a common velocity of about 7 m/s. Since the effective mass of the moving door assembly was more than seven times of the dummy's weight, the existence and positions of the test subject or the door padding conditions had little effect on the pre-programmed velocity pulses.

DUMMY TEST RESULTS

A total of seven SID dummy tests were conducted so far. The interfaces between the door and test subject were divided into four categories: (1) 4-inch space but no padding; (2) 4-inch soft paper honeycomb pad but no space; (3) 3-inch ARCEL pad with 1-inch space and (4) 4-inch space, no padding and no shoulder engagement. The test conditions and peak values are summarized in Table 1.

Effect of Space and Padding

Comparisons are made to the following three test conditions: (1) 4-inch space but no padding; (2) 4-inch soft paper honeycomb pad but no space and (3) 3-inch ARCEL pad with 1-inch space. The stiffness of the soft paper honeycomb, specified by the manufacturer, were 15 psi for the thorax and abdomen beams and 23 psi for shoulder and pelvis beams. However, the actual crush stiffness of these paper honeycombs were found to be 8-11 psi and 19 psi, respectively, after initial crush (Cavanaugh et al., 1992). To avoid confusion, the manufacturer's ratings (15 and 23 psi) were used in this paper to identify the paper honeycomb. The ARCEL pad has a typical force-deflection curve of resilient foam materials, and the stiffness was found to be about 28 psi at 35 % compression (Cavanaugh et al., 1992). This ARCEL pad was referred to as a stiff pad since an elderly occupant's chest hardly crushed a 22-psi ARSAN pad (Cavanaugh et al., 1993b). To better clarify the padding used in the tests, these three impact interfaces are called rigid wall, soft pad and stiff pad, respectively, for the discussion followed.

Figure 4 is a comparison of TTI(d) of the SID dummy for the three cases. If there was no padding available, TTI(d) was very high. The 4-inch space did not serve to reduce TTI(d), perhaps due to the fact that the door started to contact the dummy at about 23 ms after impact when the door had a velocity peak of 10 m/s. If a 4-inch soft pad was used, TTI(d) was much lower than that of the rigid wall impact. However, the soft pad bottomed out, and TTI(d) was still higher than 85 g's. When a 3-inch stiff pad was used, TTI(d) was the lowest of the three cases and was below 85 g's of the Federal requirement. However, the 3-inch thorax stiff pad deflected 1.9 inches detected by a string pot, and the stiffness of the pad at 1.9-inch deflection was more than 40 psi. Since the tolerance for the human chest is below 20 psi (Cavanaugh et al. 1993b), an intruding door would crush an occupant's chest rather than the 40-psi pad, and the stiff door padding would behave like a rigid wall.

Figure 5 presents a comparison of ASA. Again, ASA was very high if there was no padding available. However, ASA and TTI(d) had an opposite trend when the impacts with a soft pad and a stiff pad were compared. The soft pad provided a lower ASA but a higher TTI(d) than the stiff pad, which was consistent with the finding in the Heidelberg type sled tests by Cavanaugh et al. (1993a). However, ASA was more than 40 g's for all of the three cases, which suggested that there was a high risk of serious chest injuries (Cavanaugh et al. 1993a)

Effect of Shoulder Engagement

King et al. (1991) and Huang et al. (1994) have pointed out that the low window sill may eliminate shoulder engagement and cause severer chest injuries. Using a lumped mass and a MADYMO human model, they found that the shoulder provides an important load path to the chest and without shoulder engagement, the force on the thorax would be 45 % higher. In order to simulate no shoulder engagement in the sled-to-sled test setup, the shoulder beam was removed, as shown in Figure 6. Although the SID dummy does not have a realistic shoulder, dummy tests are still helpful in understanding chest responses before complex and expensive cadaveric tests are conducted.

There was no shoulder engagement in Runs 7 and 8. The door was rigid but there was 4-inch space between the door and dummy. When the impacts with shoulder engagement (Runs 2 and 3) and without shoulder engagement (Runs 7 and 8) are compared, the impact without shoulder engagement provided a much higher TTI and ASA than that with shoulder engagement, as listed in Table 1. It is not known if the low window sill of a small car is partly responsible for a possible high TTI(d) in the FMVSS 214 dynamic test. Figure 7 shows the comparison of thoracic contact forces for the impacts with or without shoulder engagement. As can be seen in the figure, if there was no shoulder engagement, the force on the thorax beam was 100 % higher. When the shoulder and thorax contact forces were summed up for the impact with shoulder engagement, as shown by the dashed line of the figure, the summed force was very close to the thorax contact force for the impact without shoulder engagement. This implied that, for the SID dummy, all the force at the shoulder level would go to the thorax if the shoulder did not contact the door structure.

Sled-to-Sled Tests vs. Heidelberg-Type Tests

It should be pointed out that in the Heidelberg tests, the subject had a nominal constant velocity of 9 m/s before impacting a stationary wall, while in the sled-to-sled tests, the subject underwent a velocity pulse with the first and second velocity peaks of 10 m/s and 7 m/s, respectively. Three impact cases were compared: (a) rigid wall impacts: rigid wall (Heidelberg) vs. rigid wall and 4-inch space (sled-to-sled); (b) soft pad impacts: 4-inch thick 15/23 psi paper honeycomb (Heidelberg) vs. 4-inch thick 15/23 psi paper honeycomb without space (sled-to-sled); (c) stiff pad impacts: 3-inch thick ARCEL (Heidelberg) vs. 3-inch thick ARCEL with 1-inch space (sled-to-sled). The Heidelberg type sled test results can be found in Cavanaugh et al. (1992).

Figure 8 shows the comparison of TTI of sled-to-sled and Heidelberg type tests. Sled-to-sled tests provided a higher TTI for all of the three cases: rigid wall, soft pad and stiff pad impacts. ASA had a similar trend, as shown in Figure 9. However, for the rigid wall impacts, the contact force on thorax was less in the sled-to-sled tests than in the Heidelberg type tests, as shown in Figure 10. The summed forces of shoulder, thorax and abdomen in the sled-to-sled tests had a similar peak and a shorter duration than in the Heidelberg type tests, as shown in Figure 11. Further investigation is needed to understand the differences between the forces and TTI or ASA when comparing the sled-to-sled tests to Heidelberg-type sled tests.

CADAVERIC TEST RESULTS

Two cadaveric tests, using the same velocity pulses (Figure 3), were conducted using this sled-to-sled setup. The preparation of cadavers and infection control followed the procedures developed by Cavanaugh et al. (1990) and Cavanaugh and King (1990). The cadavers were instrumented with multiple accelerometers and an EPIDM chest band with 40 strain gages. However, due to the failure of a new on-board data acquisition system, 48 channels, including barrier forces and cadaver accelerations, were lost for both tests. The chest band data were acquired by another data acquisition system and the chest deformation contours were available.

In one cadaver test, there was 102 mm (4 inch) space, but no padding, between the rigid door and the test subject. The cadaver was a 66 year-old male and had a body weight of 122 lbs. The autopsy data showed that there were: (1) 11 rib fractures on the impacted side; (2) 3 rib fractures on the non-impacted side; (3) multiple fractures in the superior ramus of pubis and (4) a separated disc between C4 and C5. There was no observed injury in the internal organs.

In the other cadaver test, there was a pad of 102-mm thick (23 psi paper honeycomb for the shoulder and pelvis beams, 15 psi for the thorax and abdomen beams), but there was no space between the simulated door and the test subject. The cadaver was a 59 year-old male and had a body weight of 126 lbs. The injuries included: (1) 10 rib fractures on the impacted side; (2) 4 rib fractures on the non-impacted side and (3) fracture and separation on the impacted side clavicle. There were no injuries in the neck and pelvis and no observed injuries in the internal organs.

Figures 12 and 13 show the chest deformation contours for the rigid wall impact and padded wall impact, respectively. As can be seen in the figures, there was a severer deformed shape in the impacted side of the rigid wall impact. In the padded wall impact, the sternum bulged out more and the non-impacted side had more deflection than that of the rigid wall impact. It is not known if this was due to a longer impact duration in the padded wall impact. Further studies are needed to understand if the non-impacted side deflection of the chest would be an indicator of non-impacted side rib fractures. The bulging sternum in the chest contours was consistent with the finding by Cavanaugh et al. (1990) that the peak sternum-X acceleration was a good discriminator of chest injuries.

DISCUSSION

Modeling of a door velocity pulse is important in a side impact sub-system test methodology. The sled-to-sled setup has been shown to be able to successfully simulate such a pulse. However, this setup required a significant modification to the current sled test configuration. Simplification of the current design could reduce hardware requirements.

Using the door velocity profile of Figure 3, 4-inch space between the driver and the door is not enough to reduce impact severity. Six or more inches of space is needed to avoid the peak velocity. However, if a driver stretches his arm over the window sill and lean against the door, the space is eliminated. This is the severest sitting position since there is no space available and no shoulder engagement. The chest will sustain 100 % more contact force since the shoulder load path is eliminated. The current Federal regulation does not address the out-of-position problem. Due care should be taken when designing car structures, especially side airbags. Four inches of soft padding is not sufficient at this impact velocity of 10 m/s since it bottomed out in the cadaveric test (Figure 14). Stiffer padding is not recommended. 40-psi padding appears to be "soft" for the SID dummy and provided a TTI(d) of less than 85 g's. However, this pad would act like a rigid door for an elderly human occupant. When selecting a pad, its stiffness should be below that of the human tolerance.

To reduce impact severity, the velocity profiles should be modified by appropriate modifications to the car structures. The first velocity peak should be lowered and the duration of the first velocity peak should be shortened. Soft padding should be thick enough so that it does not bottom out. A special seat design, which can guarantee an enough space between the driver and the side door, may help solve the out-of-position problem.

The sled-to-sled tests, using the current velocity profiles with a velocity peak of 10 m/s, are severer than the 9-m/s corresponding Heidelberg type sled tests if ASA and TTI in the SID dummy are appropriate injury indicators. Theoretically, a 9-m/s Heidelberg type sled test should be equivalent to a sled-to-sled test with a 9-m/s constant door velocity. However, the door has a velocity pulse instead of a constant velocity. The relationship between the Heidelberg type and sled-to-sled tests should be studied in greater detail.

CONCLUSIONS

1. A sled-to-sled side impact sub-system setup has been designed and fabricated at Wayne State University. It has been shown to be able to simulate typical side impact velocity profiles. It can be used to study many concepts relevant to the design of door, armrest, padding and side airbags. However, this setup requires significant modification to the current sled configuration.

2. Using the current velocity profiles and the SID dummy, it is shown that: (1) TTI and ASA are lower if there is padding available; (2) TTI and ASA have an opposite trend when predicting the benefit of stiff and soft padding - a stiff pad provides a lower TTI but a higher ASA than a soft pad.

3. The shoulder provides an important load path in protecting the thorax. Without shoulder engagement, the thorax will take up all the shoulder load in addition to the original thorax load, for the SID dummy.

4. Using the current velocity profiles with a velocity peak of 10 m/s, a sled-to-sled test is severer than a corresponding 9-m/s Heidelberg type sled test.

5. In order to reduce impact severity, the door-occupant contact velocity should be reduced and enough soft padding or equivalent should be used so that the padding does not bottom out.

ACKNOWLEDGEMENTS

This work was supported by the Centers for Disease Control (Grant No. CCR 502347). The chest band was provided by NHTSA. We wish to thank the Bioengineering staff who contributed to this work.

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Table 1 Summary of the sled to sled test data for the SID dummy

Run No.	Test Date	Shd Engage-met	Pad	Space (mm)	Striking Sled V (m/s)	Door V 1st Peak (m/s)	Door V nd Peak (m/s)	Door Intrusion (mm)	Shd Force (kN)	Tho Force (kN)	Abd Force (kN)	Pel Force (kN)	Knee Force (kN)
SSD02	5-4-94	Yes	No	102.0	12.8	9.8	6.7	158.8	14.74	9.63	15.08	22.17	13.31
SSD03	5-9-94	Yes	No	102.0	13.0	10.1	6.8	162.6	16.95	---	16.83	23.75	---
SSD04	5-11-94	Yes	4" 15/23 PH	0.0	13.0	10.1	6.9	160.3	10.50	10.81	3.55	6.86	4.07
SSD05	5-13-94	Yes	3" Arcell 512	25.4	13.3	10.3	7.0	162.2	13.04	11.02	6.31	12.22	5.75
SSD06	5-16-94	Yes	3" Arcell 512	25.4	13.0	10.4	6.9	178.0	10.53	11.40	5.36	13.16	5.57
SSD07	5-17-94	No	No	102.0	13.0	11.7	7.1	170.0					
SSD08	5-20-94	No	No	102.0	13.0	10.0	7.0	179.3	---	25.19	15.50	22.27	20.03

Run No.	Tho Pad Defl. (mm)	Abd Pad Defl. (mm)	Up Rib Prim (g's)	Up Rib Back (g's)	Lo Rib Prim (g's)	Lo Rib Back (g's)	T12-Y Prim (g's)	T12-Y Back (g's)	Pel Prim (g's)	Pel Back (g's)	TTI (g's)	ASA10 (g's)	ASA15 (g's)	ASA20 (g's)
SSD02	---	---	225.3	203.1	207.0	215.7	131.6	133.2	172.4	177.2	178.5	119.4	122.5	121.6
SSD03	---	---	231.65	212.14	209.7	220.7	146.9	148.7	177.4	---	189.3	129.5	134.5	135.2
SSD04	---	---	126.66	115.44	125.8	128.6	79.2	80.1	52.4	53.1	102.9	40.3	49.8	54.9
SSD05	---	---	69.19	63.95	72.6	74.6	77.8	78.7	81.9	---	75.2	62.3	67.7	70.7
SSD06	47.66	---	74.99	66.16	74.3	75.6	74.6	75.4	80.3	81.1	78.0	62.0	64.8	67.7
SSD07	---	---	174.11	162.55	243.0	254.5	170.8	172.7	180.1	183.9	206.9	144.6	152.1	154.8
SSD08	---	---	162.12	151.75	249.6	256.5	180.2	181.8	190.0	194.4	219.8	151.8	160.1	163.8

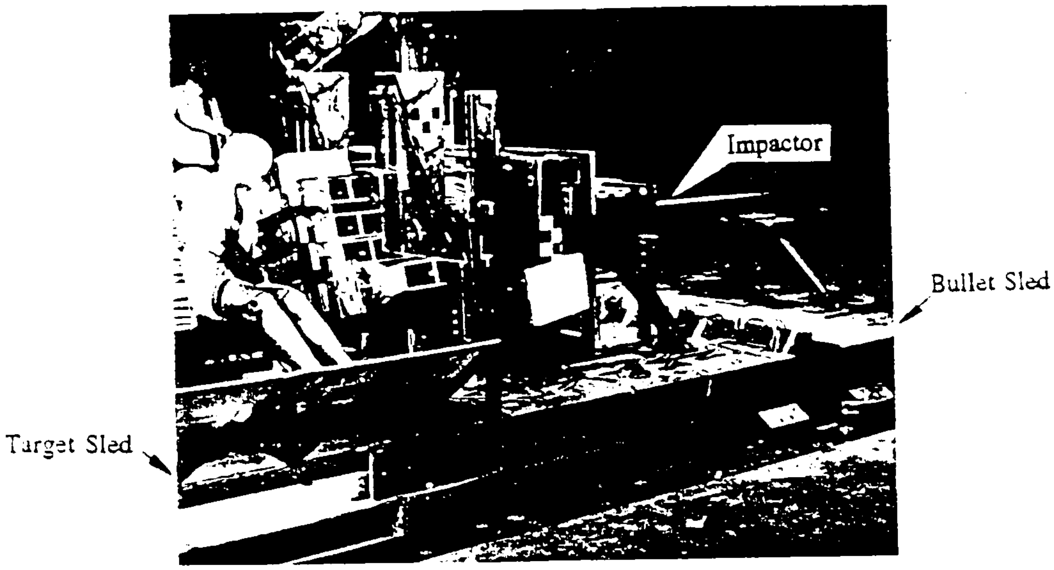
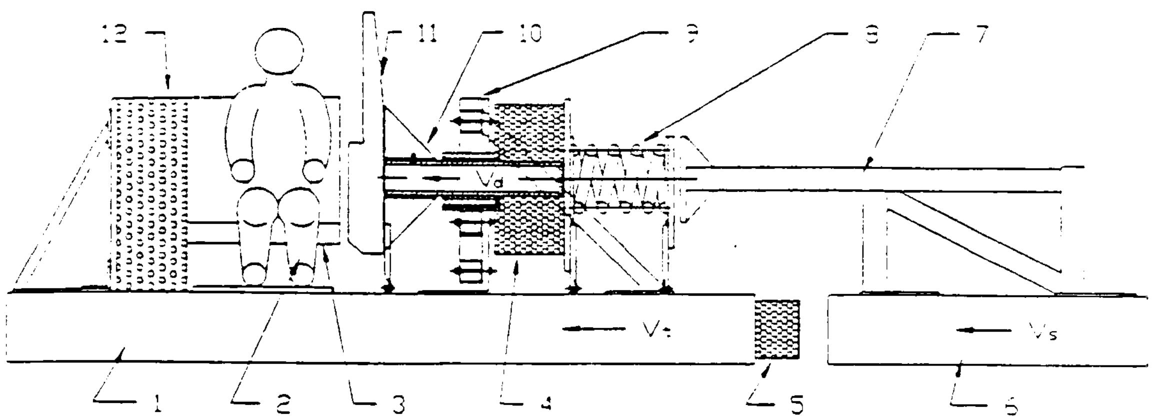


Figure 1. The CDC/WSU sled-to-sled test setup.



1. Target Sled 2. Test Subject 3. Seat 4. Energy Absorber (EA1) 5. Energy Absorber (EA2)
6. Bullet Sled 7. Impactor 8. Spring 9. Main Support 10. Piston 11. Door 12. Energy Absorber (EA3)

Figure 2. A simplified concept sled-to-sled setup.

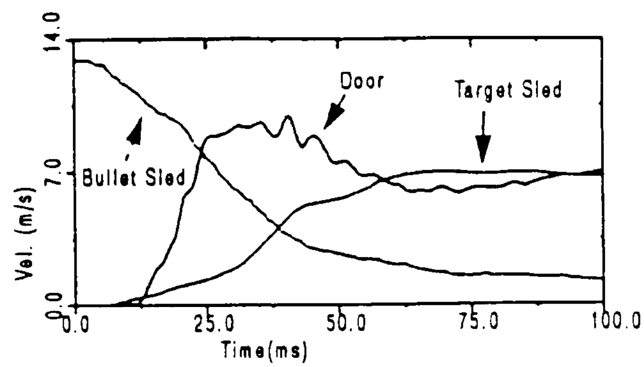


Figure 3. Velocity profiles used in the dummy and cadaveric tests.

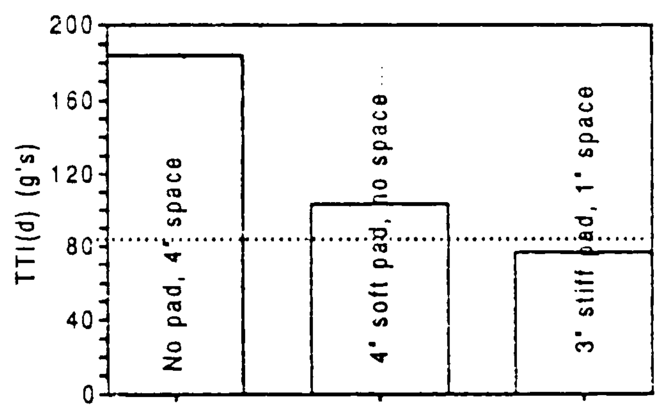


Figure 4. Effect of padding and space: a comparison of TTI(d).

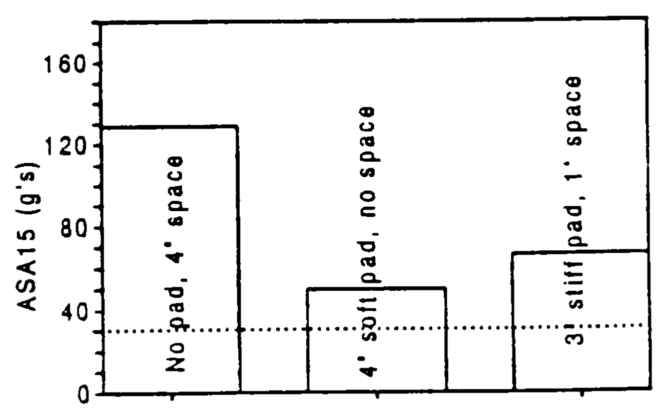


Figure 5. Effect of padding and space: a comparison of ASA.

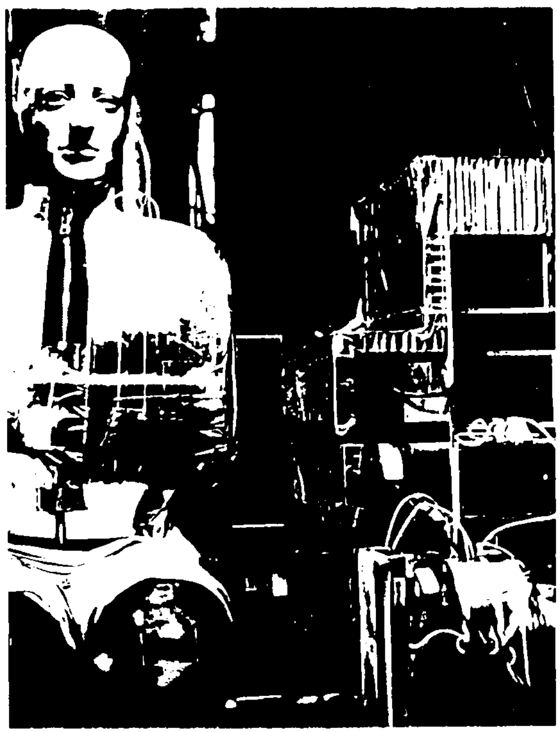


Figure 6. Test setup for no shoulder engagement.

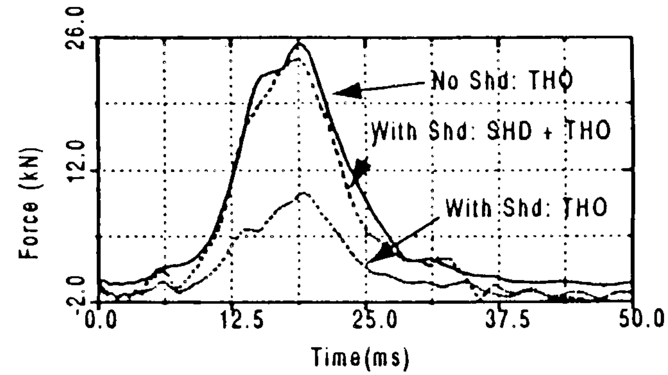


Figure 7. Comparison of the thoracic forces with or without shoulder engagement.

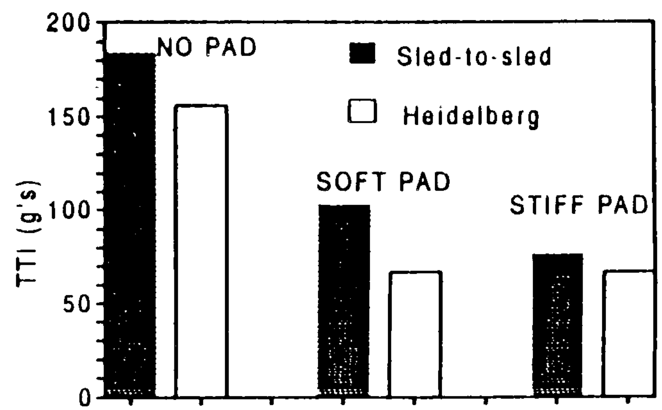


Figure 8. Comparison of the sled-to-sled and Heidelberg type tests: TTI.

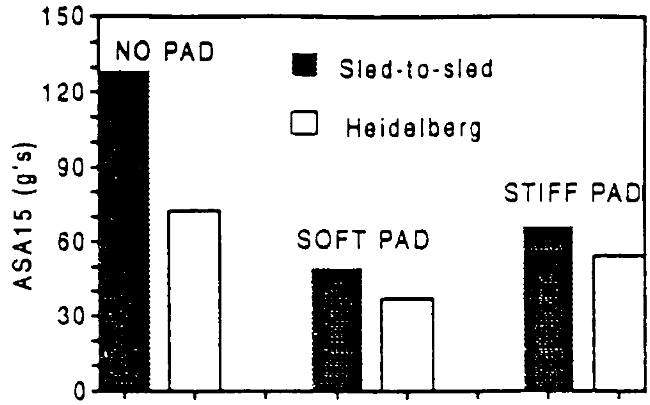


Figure 9. Comparison of the sled-to-sled and Heidelberg-type tests: ASA.

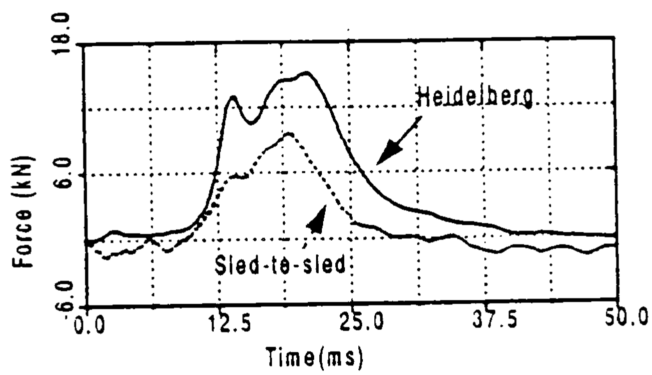


Figure 10. Comparison of the sled-to-sled and Heidelberg-type tests: thoracic forces.

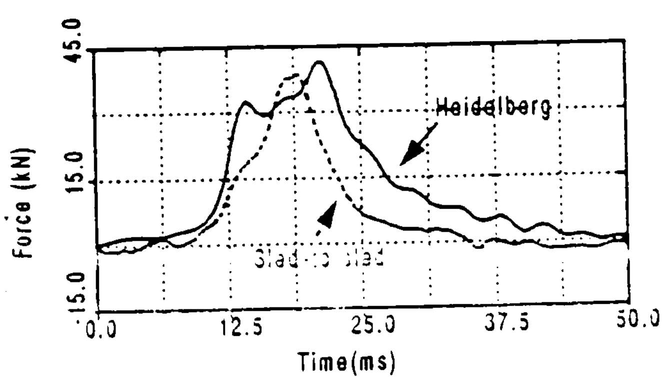


Figure 11. Comparison of the sled-to-sled and Heidelberg-type tests: sum of the shoulder, thoracic and abdominal forces.

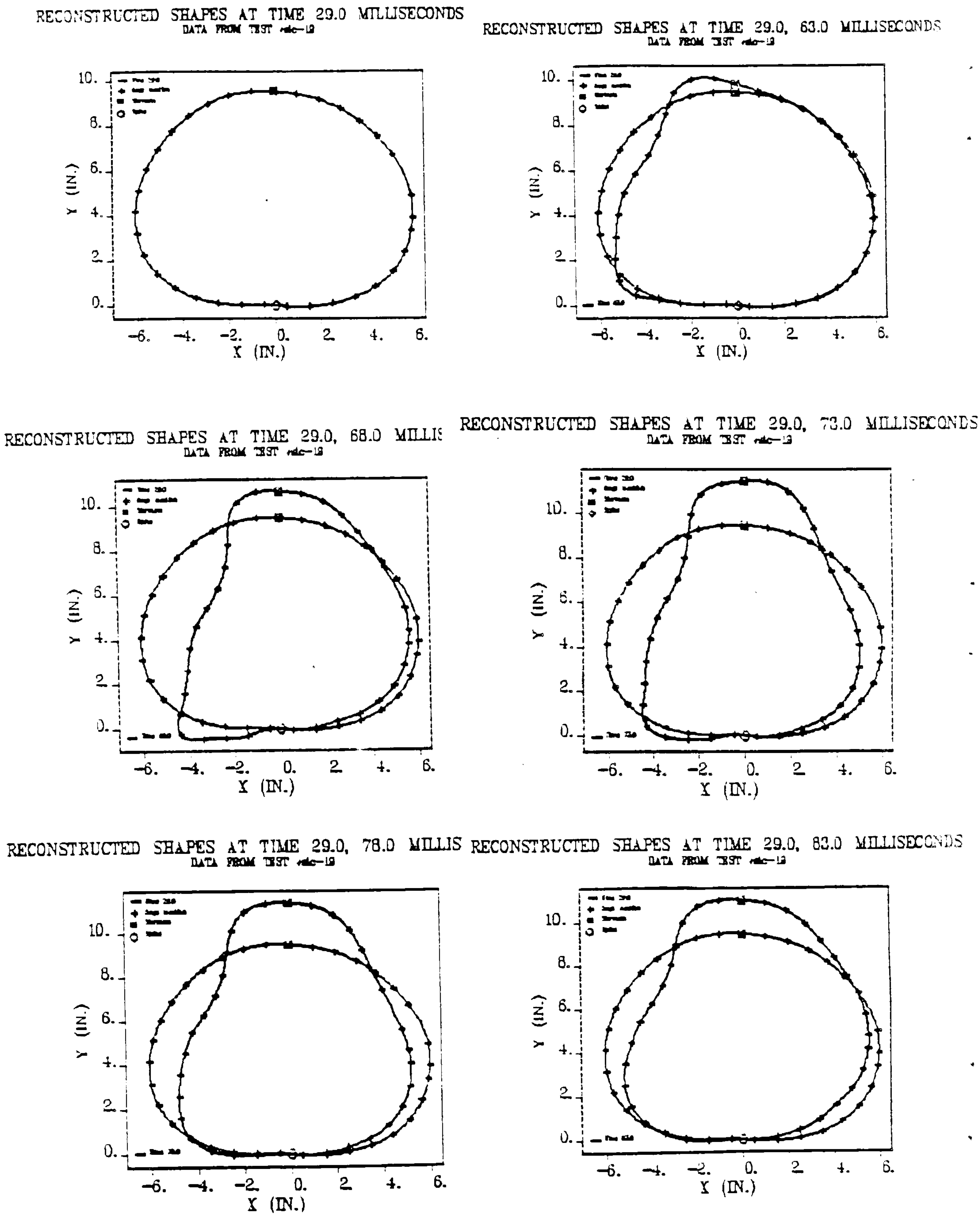


Figure 12. The chest deformation contours for the rigid wall impact.

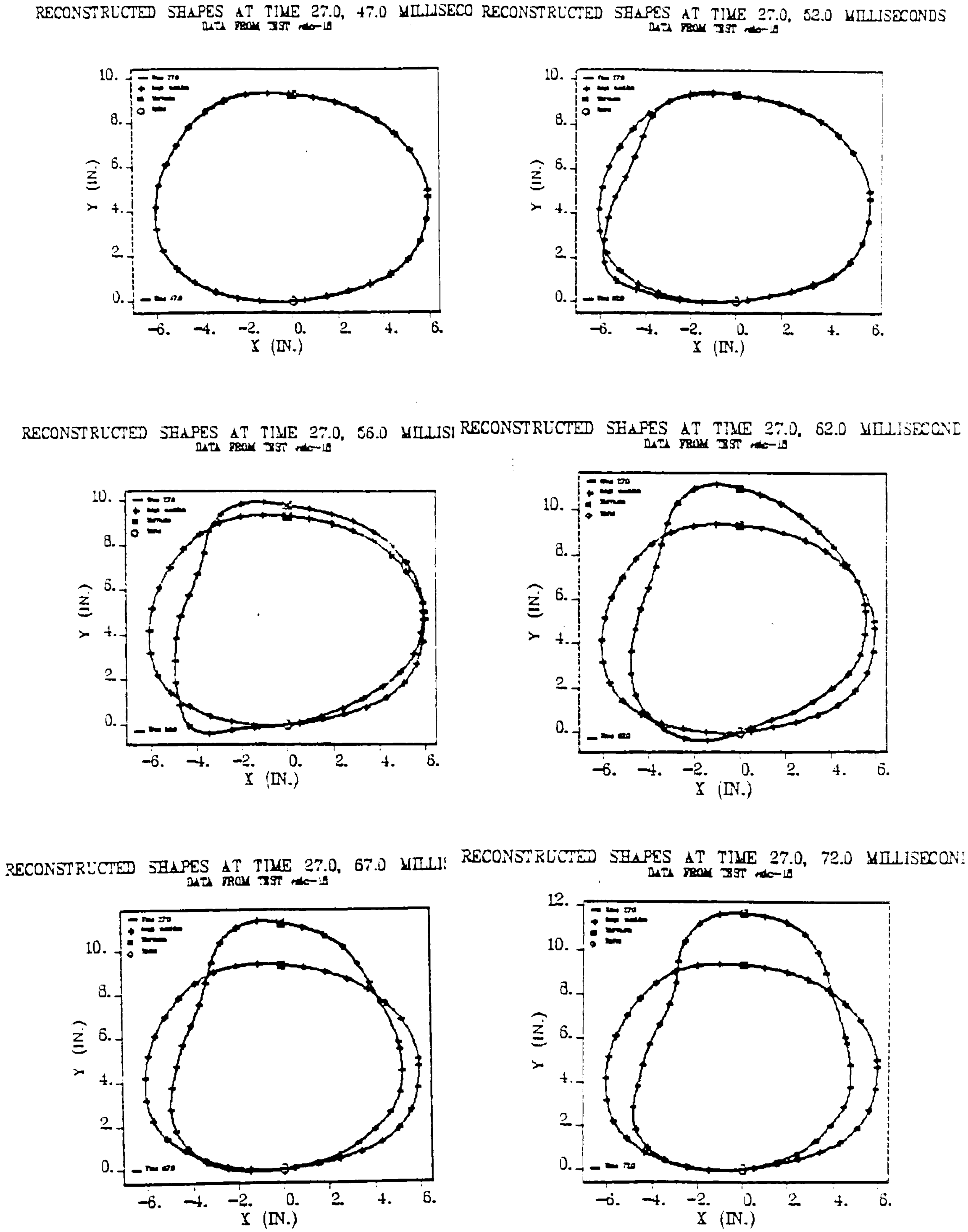


Figure 13. The chest deformation contours for the padded wall impact.

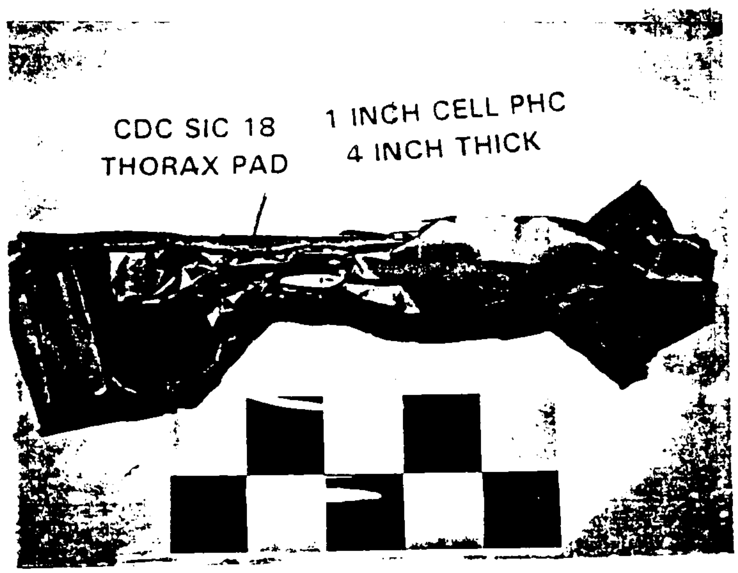


Figure 14. The four inches of 15-psi paper honeycomb thoracic pad used in the cadaveric test.

DISCUSSION

PAPER **Side Impact Subsystem Test Device - Sled To Sled Test Set Up**

PRESENTER: Yue Huang, Wayne State University

Q: Narayan Yoganandan, Medical College of Wisconsin
I saw that you showed a similar number of rib fractures occurred in both the cadaver tests. Do you mean to say that the severity of the fractures were similar or the number of fractures were similar?

A: The number of the rib fractures.

Q: In which case, they are more severe?

A: If there is no padding, there are eleven rib fractures on the impacting side, three rib fractures on the non-impacting side. But with the padding, ten rib fractures on the impacting side but four rib fractures on the non-impacting side. So, we average fourteen rib fractures for the whole torso.

Q: On the contralateral side, what kind of fractures did you have when you say rib fractures? Were they hairline or were they displaced? The pleura was torn? Did you get any vital organ injuries? What kind of injuries had you gotten on the contralateral side?

A: Actually, I did not look at the data very much because we just listened to get the data, but as I remember, I could not guess. How would you like me to answer that question?

Q: I want to know what kind of fractures were there on the contralateral side, the types of fractures. Did you see any internal vital organ trauma, like laceration of the liver, for example, in one test in contrast to the other test?

A: I believe the internal organs didn't tear.

Q: So there was no internal organ trauma at all.

A: We would have noticed that.

Q: So there are only basically minor rib fractures.

A: Yes.

Q: Thank you.

Q: Guy Nusholtz, Chrysler Corporation
What was the compressive PSI of your different paddings, your stiff padding, soft padding?

A: I'd say for the soft padding, we use the manufacturer rating padding 23 PSI for the shoulder and pelvis and 15 PSI for the thorax and abdomen piece and, the so-called stiff padding, I see are five and two at 35% compression, about 30 PSI at about 35% compression.

Q: So that's the yield. That's the knee. You've got your initial linear rise.

A: Yes, linear rise.

Q: You have the plateau and then densification?

A: Yes.

Q: It's not necessarily where the yield is?

A: Yes, because it continues to increase.

Q: Typically, foam is linear, then it's got a knee and then it goes up and then it densifies and becomes very stiff. You classify it by the knee, but you're classifying it somewhere past that.

A: Normally, 35% of compression.

Q: Did you do anything to characterize the two cadavers you use and make a comparison, like some sort of bone structure or x-rays or something?

A: Yes, normally we run the rib bending test after the impact, but I don't have the result right now.

Q: OK. Thank you.

Q: Rolf Eppinger, NHTSA
It is a very interesting design concept with this doubly moving sled. As I recall, Dynamic Science, about ten to fifteen years ago, also created what they called a doubly articulated sled with very much the same design concept as you had. The major difference was that the movable part that the bullet sled hit was actually a side door of a vehicle. That side door then was held with forced crushable elements to the main mast of the sled. That concept allowed one to have the inertial weight of the door exactly as you would have in a production vehicle. The question I have would be, with your articulated sled, how much mass is associated with the initial moving part that you consider the door? In other words, door beam, load cell, and all of that. How much would you think that mass would modify the kinematics or the load patterns from contacting an actual production door?

A: When we look at the safe or FMVSS 214 Test and, we say, to look at doors, it is not a big deal, maybe 40 lbs. It is really light, right?

Q: Yes.

A: But, however, if we can still link the barrier force with the intruding door, that's a huge mass. We cannot simply assimilate here the FMVSS 214 Test by saying moving parts only weigh 40 lbs. So that, initially, when I put a dummy or a test subject in the seat, I hope the subject will not affect the velocity pulse I want. If I program the velocity pulse, this pulse will be kept in synch for all of the case, say for with the padding, no space or space or whatever, so that, initially, I want a moving part which should be at least five to six times of the dummy weight so that the dummy will not affect the program velocity. So, in our case, the inertia of the moving parts are about 800 lbs.

Q: Eight hundred pounds, yes. If you would take another perspective in looking at the whole motivation for this process is when people put accelerometers on the outside of the door and the inside of the door, when it contacted dummies in a full car-to-car crash or simulated 214 system, and it looks like you crushed the door from the outside towards the inside. Then the entire door moves towards us now inertially, stationary dummy, and then contacts the dummy and then sweeps him to the side.

A: Yes.

Q: Part of this velocity drop, if you look at it from another perspective, is actually at the inside of the door. There is some residual crushed space left, and the door is actually crushing back towards the outside and reducing that drop in velocity. So what you attempt to do, by creating a large force as an interaction to get the velocity drop, was actually a velocity drop achieved by the door crushing back towards the rigid barrier. Do you think that would have a strong influence in the differences between the two systems, trying to simulate the real vehicle accurately?

A: As I see the problems, basically what we can do in the future is that we can just put a real door on the wall. We can pre-crush the real door or the door from a FMVSS 214 Test and then put it on the wall. That's what I believe.

Q: Why don't we just suggest somewhere in the dusty corners of Wayne State is a doubly articulated sled, or should still be. That we had Wayne State build. It would be nice to make those comparisons between the two systems. If you're trying to design a sled system, that says I can now design padding with that. Otherwise, you still have to design the padding on the car I believe. Thank you.

Q: Jeff Crandall at UVA
We are currently using honeycomb in our knee bolster as our deformable material for that particular stroke and we found that we get a substantial spike, maybe even 50% of the constant load before the honeycomb starts to crush. You mentioned before, pre-crushing of the honeycomb, but I think I noticed in your pictures that it appeared maybe that what you're actually using in your tests wasn't pre-crushed.

A: Yes. It was not pre-crushed.

Q: Could you give me your rationale behind that? Do you not see a spike in your particular honeycomb or is that just acceptable?

A: From a pendulum test, we got a spike, but from the sled test, normally, we do not see it because it is not a flat surface; normally we are dealing the with cadaver. The cadaver may be crushed first and I don't know. We do not see this spike in the cadaver test.

Q: OK. It looked to me like you had some metal pieces on top of the outside of the honeycomb.

A: Yes.

Q: I guess it would distribute the load and make it more or less, to the honeycomb, a flat surface when it began to crush, so I would suspect. Does that not cause an instantaneous increase in your velocity and then a small fall off spike?

A: The whole structure is quite rigid and the padding we know (in fact, the whole structure) would not be affected by the padding. I don't really know how to answer your question exactly enough. From sled to sled or from the hybrid sled test, we did not notice the spike, but from the pendulum test we do.

Q: OK. Thank you.

Q: Tony Sances, Medical College of Wisconsin
I understand that you are suggesting that both the stiff structure and padding would tend to mitigate injuries. Is that my understanding?

A: Yes. For this particular velocity pulse, if you use the SID dummy to evaluate the injury potentials and TTI and ASA as injury predictors, we say they are more than 100% of the human torus limbs.

Q: Have you identified the characteristics of the structure and the characteristics of the padding that you feel would be appropriate?

A: We did not go to that file right now.

Q: Thank you very much.